# A Brief Introduction to the Principles of Woodwind Instrument Design

Chad R. Sobodash

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## 1 Introduction

The creation of musical instruments is a highly touted profession. Despite the forecast decline of instrument building and repair positions, mankind will always need this task to be done. Ever since traces of man have existed, so has music. The first flute was created thousands of years ago, when Neanderthal man bore holes in a hollow bone. Blowing on the end created sounds pleasing to the ear. From that moment, music and its creativity changed forever.

## 2 Principles of Sound

To understand woodwind instruments, you must first understand the basic principles of sound. Sound is caused by disturbances or vibrations in the air (sound waves), which then vibrate against parts of our eardrum. A mechanical link of bones sends this vibration to the cochlea: a fluid filled conical tube. The membrane near the window of the cochlea is narrow, stiff, and responds to high pitches. The membrane in the middle responds to midrange pitches. The membrane near the end of the cochlea is wide, flexible, and responds to low pitches. Frequency, the number of vibrations per second, is measured in cycles per second or Hertz (Hz) and is a very important factor in how we perceive sound. The pitch of sound is almost entirely determined by frequency. Higher frequency means higher pitch and lower frequency means lower pitch. For example, 440 vibrations per second (440 Hz) registers as note A in the G clef. 220 Hz is heard as A one octave lower, and 110 is heard as one octave below that. Humans can hear sounds between 15 Hz to 20 kHz (Kilohertz). A contrabassoon can play Bb0 at 29 Hz, the lowest playable note on a woodwind instrument. When the note is played loudly, it is possible to hear the pulses of pressure as the reed opens and closes 29 times per second. Human ears are most sensitive to sounds between 1 and 4 kHz, which is why extremely high pitches can cause pain. This is also why instruments with a lower range have to be played louder to be heard, than instruments with a higher range.

## 3 Acoustics of Woodwinds

Woodwinds usually have a higher range than other instruments. Woodwind instruments are essentially a long, closed, tube when the finger holes are covered. A sound wave can travel down a tube, reflect at one end and come back. It can then reflect at the other end and start over again. A shorter tube means a shorter trip between both ends, resulting in a higher pitch. In woodwinds, the tube length is shortened by opening and closing holes. However, it is possible to make a higher pitch without shortening the tube length. This is called harmonic series. This occurs by increasing pressure, which then increases motion. This makes the sound move faster, making its trip shorter. Harmonic series is only possible in flute instruments, or instruments open at both ends.

## 4 Families of Woodwinds

Woodwind instruments can be separated into three families: flute, single reed, and double reed. The flute family consists of the recorder, whistle, and other instruments requiring a stream of air striking a surface to operate. The single reed family consists of the saxophone, clarinet, and other instruments requiring a single reed vibrating against a surface to operate. The double reed family consists of oboe, bassoon, and other instruments using two reeds vibrating against each other in unison to operate. Flute instruments typically use cylindrical bodies, single reeds typically use semi-cylindrical bodies, and double reeds typically use conical bodies. There are, however, exceptions to the rules. The most obvious exception is the saxophone, which consists of a single reed on a conical body. Other interesting changes in body shape include the English horn. It consists of a cylindrical body and a bowl-shaped bell.

## 5 Flutes

The flute contains two sub-families: open and closed flutes. Open flutes consist of the transverse flute and other instruments using a stream of air which goes directly from the source to the edge. Closed flutes consist of the recorder, whistle, and other instruments in which the instrument directs a stream of air towards or over the edge. The flute is the most common starter instrument for amateur instrument makers, since materials are cheap and basic principles are easy to grasp.

## 6 Materials

The most common starter material is PVC (polyvinyl carbonate) since it is easy to obtain and work with. PVC does not require many tools to work with and is very cheap. A step up from PVC is bamboo. Bamboo is not nearly as easy to work with, and requires more patience. Bamboo is naturally cylindrical

and is ideal for flute crafting, since the grain runs perfectly vertical. Copper tubing is another choice of some flute and whistle makers. It is more costly than bamboo and requires more skill and tools to work with. It has a sharp tone, and doesn't work well with mellow flute tones. Master crafters often choose metals like silver, gold, and platinum to create their flutes from, since they usually cost more. The hardest material some crafters choose to use for flute making is glass or crystal. Years of skills are required to be able to make a perfectly cylindrical glass flute, and they cost large amounts of money. Some people have tried working with stone to create flutes, but no notable success is worth mentioning. The difference in sound occurs mainly in the surface of the material chosen. The actual consistency has nothing to do with it. Bamboo has ridges, so it deflects sound differently than PVC, which is smooth and solid. Arguably, the most important part of the flute making process is the shape of the embrochure. The embrochure is the place where sound originates, so without it, the instrument will not sound. It's best for the embrochure, no matter what its shape, to be smooth. Usually, makers will use sandpaper to smooth the surface. Or sometimes a polishing wheel (in the case of metal) will be used.

# 7 Basics of Reeds

Reeds are made of cane or plastic which is springy and vibrates on its own. They are forced to vibrate at the natural frequency of the air in the tube. When pressure decreases, the reed closes and lets less air in, and when pressure increases, the reed opens and lets more air in. Single reeds are easier to play, because they vibrate against a surface that is stationary, whereas the sides of a double reed vibrate in unison. Synthetic reeds are made from a special formulated plastic that is made in sheets. The sheets are then cut in the same way as real cane. What makes synthetic reeds so special is that they have individual fibers, just like wood. Also, they are more reliable, because they are all the same. Reeds are attached to a mouthpiece, which also plays an important role in sound production. The inside of a clarinet mouthpiece is smooth and curved, while a saxophone mouthpiece is sharp and rectangular. This makes the sound on a saxophone sharper and raspier, and the sound on a clarinet smoother and mellower. Mouthpieces are usually made from very hard plastic, or sometimes metal. Metal mouthpieces are much harder to play on, because they demand more air to vibrate. The ligature that attaches to the mouthpiece even plays a role. The ligature determines how much tension the reed has. If the ligature is tighter, the reed requires less air. If the ligature is looser, the reed requires more air. A loose reed or otherwise unnecessary leaks in the mouthpiece seal create a very airy sound, like someone blowing through the instrument with no tension on their lips. Ligatures come in different materials too. Rubber synthetics are usually more expensive, and used on bass instruments that require lower frequency. This is because they are more elastic. Metal ones are tense, and used for instruments requiring a higher frequency.

## 8 Single Reed Instruments

Single reed instruments are harder to make than flutes. Since their pressure waves are more inconsistent, it takes exact precision to make a single reed instrument with more than one octave. Single reed instruments operate from a reed vibrating up and down. When the reed slaps against the mouthpiece, it creates sound. Reeds are either made from cane or plastic, since they are flexible, but return to their shape. This is because in cane, the grain is spaced out with a sort of filler wood. The reed is held against the aperture of the mouthpiece with a ligature. A ligature is a variable width, cylindrical holster, which straps the reed to the mouthpiece. They are normally made of metal or plastic. Single reeds typically include the saxophone and clarinet families of instruments. The difference in sound comes from body shape. Clarinets have semi-cylindrical bodies, while saxophones have conical bodies. The difference usually occurs at the tip. The bell of a clarinet curves out at a higher and sharper position than others. From any other point in the body, it's a cylinder.

## 9 Double Reed Instruments

Double reed instruments are the hardest instruments to make. They have highly inconsistent pressure and motion waves. Double reed instruments have bodies that are conical. This is because pressure is so high at the reed. If the body is conical, this releases the pressure gradually. Double reeds are usually made from two thin pieces of cane surrounding a pipe (usually some kind of metal) wrapped with thread or wire. Double reeds contain two sub-families: exposed and capped. Exposed double reeds include the oboe, English horn, and other instruments whose reed is exposed to the player. Capped double reeds include the bagpipes, crumhorn, and other instruments whose reed is enclosed by a mouthpiece. Capped double reeds are the easiest to play, since exposed double reeds require perfect tension and air from the player.

## 10 Finger Hole Placement

Finger hole placement on woodwind bodies is extremely important. Pitch is determined by where the finger holes are and how big they are. There are several mathematical formulas for determining where finger holes should be placed. A common formula for the placement of holes on open instruments is V/(2L)=F, where V is the speed of sound, F is the desired frequency, and L is the distance from the embrochure to the finger hole. The speed of sound varies according to what the atmosphere is and what the temperature of the air is. This is why almost all instruments have a tuning coupler. The tuning coupler allows the body to become longer and shorter. The coupler works by separating the body into two or more parts, and allowing the parts to slip together in a two-sided housing.

## 11 Temperture

Temperature has other effects on instruments. It can distort the material from which the instruments are made, throwing their entire tuning off. If the air is very humid, then the humidity can condense inside and outside the instrument, making it almost impossible to play. The sound's reverberation isn't smooth if its path is obstructed. The temperature of the air also effects the sound production. When molecules are moving faster, then the sound can move faster. When the molecules are moving slower, then the sound moves slower. This is because the molecules get in the way of distortion.

## 12 Conclusion

The creation of woodwind instruments is more complicated than people think. When someone picks up their recorder in elementary school, they don't realize that it took 9000 years of instrumental evolution to create that instrument. Instruments are just as important, if not more important, than the music they play. Without the instruments, the music can't exist, and without the music, the instruments are useless.